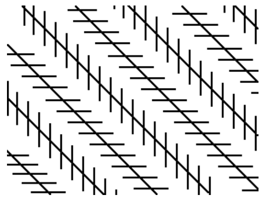
inst.eecs.berkeley.edu/~cs61c/su05

CS61C : Machine Structures

Lecture #28: Parallel Computing



2005-08-09

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Scientific Computing

° Traditional Science

1) Produce theories and designs on "paper"

2) Perform experiments or build systems

- Has become difficult, expensive, slow, and dangerous for fields on the leading edge

° Computational Science

- Use ultra-high performance computers to simulate the system we're interested in

° Acknowledgement

- Many of the concepts and some of the content of this lecture were drawn from Prof. Jim Demmel's CS 267 lecture slides which can be found at http://www.cs.berkeley.edu/~demmel/cs267_Spr05/

Example Applications

° Science
- Global climate modeling
- Biology: genomics; protein folding; drug design
- Astrophysical modeling
- Computational Chemistry
- Computational Material Sciences and Nanosciences

° Engineering
- Semiconductor design
- Earthquake and structural modeling
- Computation fluid dynamics (airplane design)
- Combustion (engine design)
- Crash simulation

° Business
- Financial and economic modeling
- Transaction processing, web services and search engines

° Defense
- Nuclear weapons -- test by simulations
- Cryptography

Performance Requirements

° Terminology
- Flop – Floating point operation
- Flops/second – standard metric for expressing the computing power of a system

° Global Climate Modeling
- Divide the world into a grid (e.g. 10 km spacing)
- Solve fluid dynamics equations to determine what the air has done at that point every minute
  - Requires about 100 Flops per grid point per minute
- This is an extremely simplified view of how the atmosphere works, to be maximally effective you need to simulate many additional systems on a much finer grid

Performance Requirements (2)

° Computational Requirements
- To keep up with real time (i.e. simulate one minute per wall clock minute): 8 Gflops/sec
- Weather Prediction (7 days in 24 hours): 56 Gflops/sec
- Climate Prediction (50 years in 30 days): 4.8 Tflops/sec
- Climate Prediction Experimentation (50 years in 12 hours): 288 Tflops/sec

° Perspective
- Pentium 4 1.4GHz, 1GB RAM, 4x100MHz FSB
  - ~320 Mflops/sec, effective
  - Climate Prediction would take ~1233 years

Reference:http://www.tc.cornell.edu/~lifka/Papers/SC2001.pdf

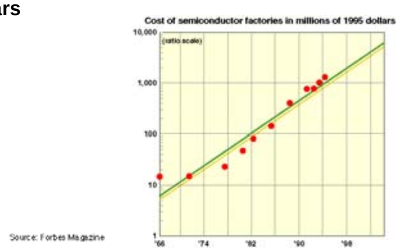
What Can We Do?

° Wait
- Moore's law tells us things are getting better; why not stall for the moment?

° Parallel Computing!

Prohibitive Costs

° Rock's Law
  - The cost of building a semiconductor chip fabrication plant that is capable of producing chips in line with Moore's law doubles every four years



How fast can a serial computer be?

° Consider a 1 Tflop/sec sequential machine:
  - Data must travel some distance, r, to get from memory to CPU
  - To get 1 data element per cycle, this means 10^{12} times per second at the speed of light, $c = 3x10^8$ m/s. Thus $r < c/10^{12} = 0.3$ mm
    - So all of the data we want to process must be stored within 0.3 mm of the CPU

° Now put 1 Tbyte of storage in a 0.3 mm x 0.3 mm area:
  - Each word occupies about 3 square Angstroms, the size of a very small atom
  - Maybe someday, but it most certainly isn't going to involve transistors as we know them

What is Parallel Computing?

° Dividing a task among multiple processors to arrive at a unified (meaningful) solution
  - For today, we will focus on systems with many processors executing identical code

° How is this different from Multiprogramming (which we've touched on some in this course)?

° How is this different from Distributed Computing?

Recent History

° Parallel Computing as a field exploded in popularity in the mid-1990s

° This resulted in an "arms race" between universities, research labs, and governments to have the fastest supercomputer in the world

Source: top500.org

Current Champions

BlueGene/L – IBM/DOE
Rochester, United States
32768 Processors, 70.72 Tflops/sec
0.7 GHz PowerPC 440

Columbia – NASA/Ames
Mountain View, United States
10160 Processors, 51.87 Tflops/sec
1.5 GHz SGI Altix

Earth Simulator – Earth Simulator Ctr.
Yokohama, Japan
5120 Processors, 35.86 Tflops/sec
SX6 Vector

Data Source: top500.org

Administrivia

° Proj 4 Due Friday

° HW8 (Optional) Due Friday

° Final Exam on Friday
  - Yeah, sure, you can have 3 one-sided cheat sheets
    - But I really don't think they'll help you all that much

° Course Survey in lab today

Parallel Programming

- Processes and Synchronization
- Processor Layout
- Other Challenges
  - Locality
  - Finding parallelism
  - Parallel Overhead
  - Load Balance

Processes

- We need a mechanism to intelligently split the execution of a program
- Fork:

```
int main(…){
  int pid = fork();
  if (pid == 0) printf("I am the child.");
  if (pid != 0) printf("I am the parent.");
  return 0;
}
```

- What will this print?

Processes (2)

- We don't know! Two potential orderings:
  - I am the child.I am the parent.
  - I am the parent.I am the child.
  - This situation is a simple race condition. This type of problem can get far more complicated…
- Modern parallel compilers and runtime environments hide the details of actually calling fork() and moving the processes to individual processors, but the complexity of synchronization remains

Synchronization

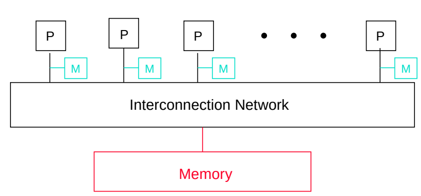
- How do processors communicate with each other?
- How do processors know when to communicate with each other?
- How do processors know which other processor has the information they need?
- When you are done computing, which processor, or processors, have the answer?

Synchronization (2)

- Some of the logistical complexity of these operations is reduced by standard communication frameworks
  - Message Passing Interface (MPI)
- Sorting out the issue of who holds what data can be made easier with the use of explicitly parallel languages
  - Unified Parallel C (UPC)
  - Titanium (Parallel Java Variant)
- Even with these tools, much of the skill and challenge of parallel programming is in resolving these problems

Processor Layout

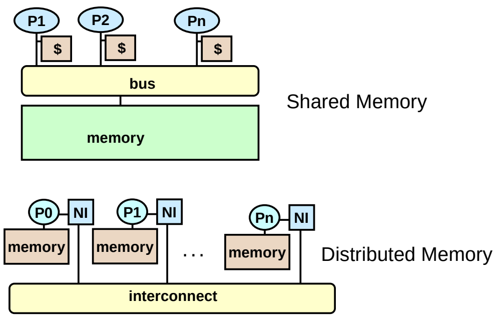
Generalized View



M = Memory local to one processor

Memory = Memory local to all *other* processors

Processor Layout (2)



Processor Layout (3)

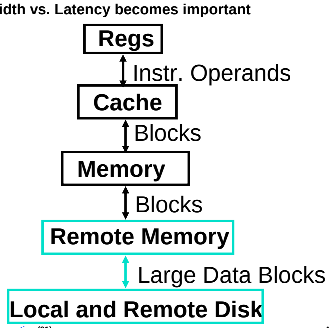
° **Clusters of SMPs**
  • **n of the N total processors share one memory**
  • **Simple shared memory communication within one cluster of n processors**
  • **Explicit network type calls to communicate from one group of n to another**

° **Understanding the processor layout that your application will be running on is crucial!**

Parallel Locality

° **We now have to expand our view of the memory hierarchy to include remote machines**

° **Remote memory behaves like a very fast network**
  • **Bandwidth vs. Latency becomes important**



Amdahl's Law

° **Applications can almost never be completely parallelized**

° **Let s be the fraction of work done sequentially, so (1-s) is fraction parallelizable, and P = number of processors**

Speedup(P) = Time(1)/Time(P)

$\leq 1/(s + (1-s)/P)$

$\leq 1/s$

° **Even if the parallel portion of your application speeds up perfectly, your performance may be limited by the sequential portion**

Parallel Overhead

° **Given enough parallel work, these are the biggest barriers to getting desired speedup**

° **Parallelism overheads include:**
  • **cost of starting a thread or process**
  • **cost of communicating shared data**
  • **cost of synchronizing**
  • **extra (redundant) computation**

° **Each of these can be in the range of milliseconds (many millions of flops) on some systems**

° **Tradeoff: Algorithm needs sufficiently large units of work to run fast in parallel (I.e. large granularity), but not so large that there is not enough parallel work**

Load Balance

° **Load imbalance is the time that some processors in the system are idle due to**
  • **insufficient parallelism (during that phase)**
  • **unequal size tasks**

° **Examples of the latter**
  • **adapting to "interesting parts of a domain"**
  • **tree-structured computations**
  • **fundamentally unstructured problems**

° **Algorithms need to carefully balance load**

Summary

- Parallel Computing is a multi-billion dollar industry driven by interesting and useful scientific computing applications
- It is extremely unlikely that sequential computing will ever again catch up with the processing power of parallel systems
- Programming parallel systems can be extremely challenging, but is built upon many of the concepts you've learned this semester in 61c